Fiscal 1999 Year- end Report to ONR Code 321OA
Physics of Seismic Interface Waves in the Surf Zone

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LONG TERM GOALS

We are working to develop the basic physics of micro seismo-acoustics so that seismic sonar can then be engineered, for the detection of mines buried in sea floor sediments and in the surf zone and perhaps on land.

OBJECTIVES

We seek to determine the potential of seismo-acoustic interface waves for the detection of objects buried just beneath the water-sediment or air-sediment interface. We seek to determine how these different wave types propagate in the surf zone sediments, and which may be best suited for mine detection and classification, and how the echo signals may best be processed to reject false targets.

APPROACH

The elastic wave equation has long been solved, for idealized media, so our primary purpose has been to explore the experimental science of seismic interface waves in real media, for which there is no theory. Exploration seismology is highly developed in the petroleum industry; but there, the interface waves are considered to be the "noise" and little has been done to understand them, only to suppress them. Although considerable knowledge has been developed for the significant interface waves in earthquake seismology, i.e. bedrock, little is known about the seismic physics of the uppermost, unconsolidated layers that are the scenarios for tactical naval and military applications. Even less is known about the reflection of energy from buried targets.

Our current approach has been experimental, but is based on theoretical research previously sponsored by ONR Code 321OA, Dr Jeffrey Simmen, PM, at the University of Texas at Austin. There, Dr. Eric Smith, a Postdoctoral Fellow developed a theory for the seismic interface wave refection from buried objects [see PUBLICATIONS, below]. He and his colleague, Preston Wilson, also developed research tools and made measurements at sea, under Professor Muir's supervision.

For the work described here, our staff included Thomas Muir, NPS Chair Professor of Mine Warfare in the Department of Physics, who teaches this subject and provides overall guidance, and was responsible for the "wet end" of the experimental research. Professor of Physics, Steven Baker, who teaches acoustical physics and acoustical engineering was responsible for the "dry end" of the

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experimental research, especially source design, digital data acquisition, recording and analysis. Professor Monique Farques, Professor of Electrical and Computer Engineering, joined the project this year and did research on the signal processing of mine echoes measured by Muir and Baker.

Since coming to NPS, Muir and Baker have collaborated to develop new research tools that include mobile instrument vehicles (amphibious tractors and trailers, as well as boats). Seismic sources and seismometers have been developed from commercial components. Computerized data acquisition and analysis systems have also been developed. Our experimental venue is the Navy beach on Monterey Bay, adjacent to the Naval Postgraduate School (NPS).

During the course of this work, we were fortunate fo have several excellent graduate students, LT Sean Fitzpatrick, USN, MAJ Patrick Hall, USMC, and LT Michail Zambartas, Hellenic Navy, who all did excellent research and wrote theses on specific topics in this area that have been and are continuing to be summarized by their professors, for publication [see PUBLICATIONS, below].

A new student, CAPT Craig Sheets, USA, has signed on for a dissertation in this research program, and is already at work, and, upon graduation, has "marching orders" to become a Professor of Physics at the United States Military Academy. He is presently involved in the wet and dry end of this research program and can be frequently found on the sea floor of Monterey Bay deploying instruments and conducting experiments. Another new student, M. Jeremie Guy, has recently arrived from France (College of Physics, Chemistry and Engineering of Lyon) and is assisting and becoming familiarized with the experiments and the signal processing of the results.

WORK COMPLETED

Our work for FY99 followed in the chain of research that ONR Code 321OA has supported with the principal investigator for the past several years [see PUBLICATIONS, below].

In FY98 (and into early FY99), we attempted to overcome the confusing and interfering effects of the excitation of many different types of compressional and shear waves in sea floor sediments, each of which travels with its own unique velocity. We attempted to discretely excite the desired interface waves, named after their discover, Lord Rayleigh. These travel in ellitical orbits in the vertical and radial planes. Several exploratory sources were developed to produce this type of excitation at the sediment surface. A number of field tests were conducted with experimental sources. Discrete Rayleigh wave excitation was not achieved in the vicinity of these sources. However, it was found that the medium itself acted as a selective filter for Rayleigh waves after a few tens of meters of propagation. It was determined that a seismic sonar for buried ordnance detection, at a few meters range, might be subject to the confusing effects of multi - wave interference and reverberation, while one operating at a few tens of meters range might be immune from these difficulties. This pointed us in the direction of more simple sources, with only vertical seismic wave excitation, but with much higher source levels, which appears to be suitable for longer range seismic sonar propagation.

During FY99, we experimented with both a device called a "force actuator" as well as a "bass shaker", from the audio industry, as candidate seismic sources. This work was done in the laboratory as well as on the Navy beach, on Monterey Bay.

In FY99, we also used these experimental tools, as well as those that prior funding from ONR Code 321OA has enabled, to measure the physical limits for long range seismic sonar operations, again on the Navy beach on Monterey Bay. We measured the spatial coherence of propagating seismic signals as a function of range and bearing.

Finally, during FY99, we did experiments on the seismic target strength of buried objects, and used the experimental results in signal processing computations that sought to extract the echo signal from the noise, reverberation, and field of false targets.

RESULTS FOR FY99

It was found that the force actuators provided a significant source vibraton (25 lbs force), enabling the excitation of seismic interface waves, much stronger than previously achieved, for potential naval applications. Two of these were used to enable the acquisition of experimental data for the three theses cited below. Although very powerful, accurate and reliable, these devices are also large, heavy and expensive.

Experiments with a much simpler source, called a bass shaker, looked promising at first, but it took quite a lot of work to determine how to use these devices in naval research. Although they are very small, light and inexpensive, they are also very nonlinear, not designed to couple to sediments, not water proofed, not documented with adequate technical information, and that which exists improperly specifies them as to their electrical properties, including how much pulse power they can handle. We have overcome these problems, and are now using these devices in a test array of eight elements, each driven at ten times the force of the previously used actuators. Since the bass shakers and their amplifiers are inexpensive, we have implemented an array of them, increasing our source capability from two actuators to eight bass shakers, now capable of beam steering. More source array elements are “in the works”.

On the Navy’s Del Monte Beach, we used these sources to measure the spatial coherence of seismic sonar signals propagating along the interface between the sediments and the overlaying fluid boundary. The spatial coherence of signals propagating in a medium, be they electromagnetic, acoustic or seismic, is a measure of how well the medium will support the operation of echo ranging devices, especially with regards to signal processing. An incoherent medium, loaded with false targets, does not offer much hope for signal processing. We found that the surf zone environment on the Navy’s Del Monte Beach offered excellent spatial coherence possibilities over long ranges and aspect angles. Before stating results, one needs to be reminded that these are NOT acoustic waves in clear water, but instead are seismic shear waves that travel in sediments with buried sea shells, pockets of differing densities, buried aquatic animal remains, rocks, refuse, etc. At a seismic frequency of 100 Hz, and a range of 30 ft. (10m), we measured coherences of 0.85 (normalized to 1.0) at aspect angles of 20 degrees, out to values of 0.75 at aspect angles of 120 degrees.

Our signal processing studies on measured seismic echoes applied a “simple discrete Hidden - Markoff Model (HMM)”, which was set up to differentiate between echoes from two types of mine - like objects we buried for experimentation in the sand sediments of the Navy’s Del Monte Beach. It was determined that accurate differentiation can be obtained, and that the results are similar to those obtained with a back - propagation neural network, applied to a different detection problem.

IMPACT - IMPLICATIONS

This research is at the center of both basic science, tactical naval and military applications and humanitarian need. It is extremely difficult to detect buried ordnance. The world's only operational systems are the marine mammal detachments of the US Navy EOD forces. The dolphins and their sonar systems are very good, but they do not like the very shallow water of the pounding surf zone and they do not operate on the beach, the sand dunes and beyond. Underwater sonar employing synthetic aperture technology has been researched and developed by CSS, and shows great promise, but applications of this technology in the surf zone and on the beach are more difficult.

In terms of basic science, we have had some much appreciated opportunities to work on this challenging and difficult problem. We are working out the theory and the experimental science of a small niche in seismo-acoustics that is uncharted. In prior ONR sponsored research, we have produced scientific products that have already gone into the annals of classical physics and oceanography. The theses cited below will find their way to the same archival destination.

In terms of tactical naval and military applications, we need but point to the projection of naval power ashore, which has historically been hampered by the deployment of mines. History has shown that third world countries, without navies, have taken control of seas and amphibious assault areas using "weapons (mines) of 19 th century technology, deployed by vessel types, known during the time of the Roman Empire".

In terms of humanitarian needs, there may be over 100 million mines and bombs left behind in 62 third word countries, most all of them buried upon the land and off the shore. Remediation is not just for highly paid defense contractors. Every day, US soldiers, sailors, airmen and marines go in harm's way to deal with buried ordnance at their foreign duty stations. The real victims are mostly civilians, who can't return to their homes in former war zones, and the casualty rate (maimed or killed) for those that do return can run as high as 25,000 a year, mostly women and children, almost 3 per hour. No satifactory technological solution exists for this problem at the present time, although a number of electromagnetic technologies are being researched and developed.

Should we be allowed to complete this research, we could put the appropriate science and technology in the hands of those who could provide robotic systems undersea, through the surf zone, and ashore to counter buried ordnance, for both tactical and humanitarian purposes.

TRANSITIONS

The present research at NPS was funded on a two year basis, starting in FY97. In FY98, the applications side of the house, ONR Code 322, under Dr Douglass Toderoff, PM, mine warfare, undertook to support continued development of the seismic sonar concept for the detection of buried ordnance, which continued an FY99. This new work augmented that already supported by Dr Jeffrey Simmen, ONR Ocean Acoustics. This transition has enabled the support of two more naval officer research efforts under professors Muir and Baker; one by LT Sean Michael Fitzpatrick, USN, and MAJ Patrick M. Hall, USMC, who both graduated in December 1998, and have returned to the fleet. LT Fitzpatrick, a naval aviator, is now the Chief Tactical Operations Officer aboard the USS CONSTELLATION, at sea. MAJ Hall is now Head of the Survivability Program for the development

of the new Advanced Amphibious Assault Vechile, at the Marine Corps Systems Command, Quantico Virginia. This grant has also provided support for the research efforts of a military officer, CAPT Kraig Sheets, USA, who has been designated, upon graduation, to be a professor of physics at the United States Military Academy. The immersion of this fine officer in navy problems will undoubtedly benefit both services. Finally, the involvement of LT Michail Zambartas of the Hellenic Navy has been a very positive experience, both for him and for Greece, as well as for the U.S. He has turned in an excellent thesis and has departed, we know not where, but if we watch the Greek Navy in future years, we should expect to see him in high command. The transitions mentioned here are of an intellectual nature, but they are not of low value; in fact, we value them quite highly.

Our most significant transition to the benefit of Navy and Marine Corps interests is expected in FY00, as we have been encouraged by our present research results to skip over many “suspected obstacles”, and just “go out and do it”. With support from Dr. Toderoff (but not specific, detailed instruction), we have jumped ahead to develop a sea going experimental system to demonstrate the potential of our method. This will be fully tested in FY00.

Having said these words, we confide that we are somewhat uncertain and unsure of the risk of “skipping over” so much uncharted undersea physics. If we succeed, we will have made a great leap forward. If we fail, we may have to return to the “drawing board”, or even be “put out to pasture”.

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